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ABSTRACT

This report summarizes the results of studies of four computer-assisted integrated learning systems (ILS) designed to teach students arithmetic: two in Israel (TOAM--distributed in the United States as DEGEM and SEMEL) and two in the United States (CCC and WICAT). The qualitative and quantitative studies identified cognitive, sociological, and affective effects, as well as several instructional design issues found to affect students' benefits from ILS. The report includes discussions of the following: (1) effects of ILS arithmetic practice, including aptitude-related differential effects, age aptitude-related differential effects, socioeconomic status effects, and gender effects; (2) students' attitudes towards working with an ILS, including attitudes toward ILS practice, comparisons of attitudes towards class and ILS arithmetic, and reasons for students' attitudes towards ILS practice; (3) instructional design and human-engineering issues of ILS, including encouraging cooperation or competition, applying time limitations for entering answers, ILS hardware and software issues, and the use of paper and pencil work while online; (4) students' ILS-related behavior; (5) teachers' ILS-related behavior, including the teachers' use of the class report, attitudes towards the class report, effects on teachers of ILS work and the class reports, competition-related behavior, and perceptions of ILS work on student learning; and (6) decision making through the computerized management of students' ILS practice. It is concluded that the ILSs available in schools are not yet mature in that none of the currently available ILS systems is satisfactory in all three of the following areas: a good curriculum, a good computerized management system, and ease of integration with regular school curriculum. (20 references) (DB)

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Cognitive, affective, and social impacts of arithmetic practice with ILS: An integration of findings from 6-years qualitative and quantitative studies.

Nira Hativa, Tel Aviv University

Paper presented in a symposium: Alternative models of using computer-based integrated learning systems (ILS) and their effectiveness. The annual meeting of the American Educational Research Association, April 1991.

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The history of the introduction of technological innovations into classrooms shows that many of them failed because they added extra burden on teachers' work. Indeed, teachers' supervising of students' work with diskette-based software loaded into stand-alone microcomputers adds a substantial burden to the regular teaching work and might be the reasons for the teachers' failure to adopt computer-based learning into their regular teaching practices. Recent studies reveal that in reality, the computers are being used only minimally and without apparent focus on educational rationales. In contrast with the expectation that the use of computers in schools should revolutionize teaching and learning, most teachers who do use computers for instruction teach the same things in basically the same ways that they have been teaching, while merely "sticking" the computer somewhere into their old practices.

Unlike stand-alone microcomputers, more systematic patterns of computer use known as (computer-based) integrated learning systems (ILS) show a high potential for facilitating teacher work and thus for adoption by teachers. In these systems which have recently become common in schools, entire classrooms use the computers simultaneously in a computer lab, on a regular basis. The "integrated," "individualized" computer software, supplied by a single vendor, contains instruction and practice problems covering a multiple-year curriculum sequence. This software is housed on a central "server" computer linked in an electronic network to up to 40 student computers (in a computer lab). Specific lessons are automatically loaded into each student's computer based on a continuous assessment of that student's previous accomplishments and current learning needs. The software "manages" students' learning with minimal teacher intervention thus requiring less teacher effort than in the other computer applications. We say that the computer "manages the students' learning" when the computer software makes decisions as to what learning unit, what type of instructional software, or what type of practice to present to the student and how to respond to the student's performance--on the basis of the student's computerized initial diagnosis, aptitude and learning-style tests, or on his or her past and ongoing

performance. The first generation of ILS during the 60's and the 70's was used particularly for either full learning or for drill and practice of basic skills. In recent years, a variety of computer applications are included in ILS, such as simulations and open tools (word processors, data base management, etc.).

Despite the important role ILS may play in school, only little research is available to guide us how to plan ILS and how to operate them in schools so that they best contribute to students' learning. The design of these systems is usually based on educational theories, on intuitive knowledge of effective teaching and learning, and on pedagogical considerations of the specific subject matter involved. We need to study how current applications of ILS in the schools actually work, what their cognitive, affective, and social effects are, and what the advantages of using these systems are, and the problems.

Features related to the hardware, software, and method of operation of ILS were found in research [2,3,4,5,6,9,10,14,15,16] to make the learning with a computer system effective for some students and, at the same time, ineffective for others with different aptitudes [5]. Even the same integrated-learning system, when operated differently at different sites, was found to produce large differences in students' learning gains (Levin, Leithner & Meister, 1986). Thus, we may conclude that different ILS's based on different sets of characteristics, or using different methods of operation, even if designed to achieve the same learning objectives, may have completely different effects on students' learning and may affect differently students of different aptitudes. For all these reasons it is important to identify the relationships between a variety of ILS characteristics and students' learning.

For this aim, I and my colleagues have studied, during the last several years, a variety of aspects (cognitive, sociological and affective) of four ILS's used for students' learning of arithmetic: two widely used in Israel (TOAM, distributed in the U.S. as DEGEM, and SEMEL) and two operated in the U.S.A. (CCC and WICAT). Our studies involved qualitative as well as quantitative methods of inquiry and identified a variety of cognitive, sociological and affective effects as well as several instructional design issues that were found to affect students' benefits from ILS. This article summarizes the findings of the research.

Although the presentation here concentrates on practicing arithmetic with ILS at the elementary school level, I believe that the issues presented here have implications for the design of ILS for other curriculum topics and for other age levels of students, as well as for other computer applications for learning, such as microworlds or tools.

Rationale for Using ILS

- It enables the integration of a variety of types of software programs in a variety of difficulty levels in the regular curriculum.

- It enable the adaptation of type and level of learning material to each student's aptitude, learning style and prior knowledge.

- It is easy to operate by teachers, saves teacher time and effort and thus bears a high potential for teacher adoption and for integration into regular teaching practices.

Summary of the Studies

(a) Effects of ILS Arithmetic Practice

1. Aptitude-related differential effects

On rate of advancement and on grade-equivalent level of the curriculum practiced.

The rate of advancement of the high achievers in the hierarchically -arranged tasks of practice is approximately twice as fast as that of the low achievers.

The differential rate of advancement is not only due to differences among students in mathematical aptitude but also to differences in their ability to adapt to the special computerized environment which is different from the paper-and-pencil environment. Low-achieving students adapt less well to the computer-based drill and practice and use it much less effectively than the high achievers do (as described below). The differences in efficacy of performance of high versus low achievers stem from differences on several characteristics that show to be essential for effective ILS work: competitive spirit; persistence; initiative in obtaining external help (teacher- and home support) when needed; responsibility for self-learning, and cognitive characteristics such as: speed of thinking, deduction ability (needed, for example, to deduce the solution algorithm from the final answers to exercises), good memory (to remember solutions to previous similar exercises), and the development of learning strategies [5].

Benefits of ILS work on promoting students' learning and cognitive skills.

Because of the aptitude-related differential rate of advancement, the high achievers receive arithmetic practice that is in advance of their concurrent class material whereas the low achievers receive practice that falls behind that material. This heads to differential benefits of the ILS work for these two groups of students:

For the high achievers: The ILS practice shows unexpectedly to be very beneficial for students with above-average arithmetic aptitude for arithmetic. Because it accelerates them to material far in advance of their grade level, all the examples they receive in the computer practice are new to them, and thus, work with ILS means for them total self-learning of new topics. This type of learning is

very challenging for them and they develop a variety of cognitive and behavioral strategies to cope with the situation [2, 5, 7].

For the low achievers: A large proportion of these students face difficulties in adapting to the ILS learning environment. The machine's inability to identify either the knowledge underlying students' answers (e.g., some answers are judged by the software to be either correct or incorrect on the basis of wrong reasons) or cognitive, affective, and sociological factors, or indeed human engineering factors, inhibits students' learning [11]. All these problems cause a sound proportion of low achieving students to be underevaluated by the ILS and consequently to be provided with learning material that is inappropriate to their real needs [4,5,6,11,10.13]. This phenomenon was identified in all four systems observed.

A decrease in students' level of practice over the summer holiday has been identified. This decrease is probably caused by decay of knowledge (forgetting) over the long holiday [9].

2. Age X aptitude-related differential effects

Because of the aptitude-related differential rate of advancement, the gap in curriculum practice between high- and low-achievers grows with years of practice and students in one classroom may concurrently get practice in material that is spread out over several grade-level curricula. We observed sixth-grade classes that had been using an integrated learning system since second grade, in which students' practice belonged to 4-5 curriculum-equivalent years [5,9]. The study [9] shows that during the first year of computer practice examined-- the third grade, there was almost no difference in yearly gains between high and low achievers (9.1 and 9.2 months-equivalent material, respectively) but during the fourth grade, the high achievers gained the equivalence of 9.3 months of class practice as compared with only 6.9 months for the low achievers. Because of the growing gap with age, a statistically significant interaction in level of computerized performance was found between students' grade level and aptitude [9].

3. SES-related differential effects

All advantaged students in all four grade levels involved in the study [9] received practice at a higher mean level than all the disadvantaged students in respective grades. This consistent difference was responsible for a main SES effect in the computerized level of practice. In addition, during the full two calendar years of the third and fourth grades, the advantaged students advanced 6.2 months-equivalent materials (approximately two thirds of a full-year curriculum) more than the disadvantaged students. An additional contribution to increasing the gap between high- and low-SES students is the feature of forgetting over the summer holiday. This shows only for disadvantaged students and is consistent throughout the four grade-levels studied [9]. The growing gap in level between the two SES groups when progressing from third to fourth grade, was

responsible for the significant grade-level X SES interaction. This result agrees with findings of previous studies (e.g., Spady, 1973) that students of higher SES background benefit from the use of technology more than students of low SES background.

4. Gender-related differential effects

Throughout the four years of the study [9], boys performed at higher levels than girls and advanced faster than girls in the practice material. Statistically significant interactions of grade level X gender indicate that the gap between boys and girls in yearly gains grew significantly when advancing from third to fourth grade.

(b) Students' Attitudes Towards Working with ILS

Two studies [8,13] inquired into both WICAT and TOAM students' attitudes towards the ILS work, using questionnaires. The following is a summary of some of the results.

1. Attitudes towards the ILS practice

Approximately 67% of the WICAT students like to work with the ILS and 20% dislike it. Similar attitudes are expressed by the TOAM students-- 75% and 15% respectively. Breaking these findings for TOAM students on achievement, SES, age and gender show that: (a) The proportion of high achievers who like to work with the system is much higher than of that low achievers (92% vs. 61%); (b) students of low SES like it proportionally more than students of upper middle SES (79% vs. 61%), and this SES-related difference is statistically significant at the .001 level; and (c) no significant age- and gender-related differences have been observed [8].

2. Comparisons of students' attitudes towards class and ILS arithmetic

Fifty eight percent of the WICAT students but only 20% of the TOAM students prefer arithmetic on the computer to that in class and 13% versus 36% respectively show the opposite preference. Breaking this result on achievement for the TOAM students, a significantly higher proportion of high achievers than of low achievers (29% vs. 11%) prefer the ILS arithmetic to that in class. No differences were observed on the basis of either gender, SES, or grade level.

A high proportion of both the WICAT- and the TOAM students (78% and 75%, respectively) believe that the computerized practice teaches them to solve new types of examples not yet learned in class. This learning takes place through trial-and-error, and through teacher's explanations by the teacher in the computer lab (TOAM students also use home support). Breaking this result for TOAM students on achievement shows that high achievers believe by significantly (at the .05 level) larger proportions than low achievers (85% and 57%, respectively) that they learn to solve new types of examples through the computer work. However, no significant differences were found on

SES, age and gender. These results mean that for the better students, much more so than for the lesser students, the computerized drill-and-practice serves as a challenging source of new learning.

Sixty percent of the WICAT students and 73% of the TOAM students believe that the computerized practice helps them with class arithmetic through making them understand the classwork better. Breaking this finding on achievement for the TOAM students reveals that 78% of the low achievers but only 54% of the high achievers believe in the contribution of the ILS work to their performance in class arithmetic. This difference may be due the fact that because the ILS practice the high achievers receive is far beyond the material learned in class, it does not contribute to their class arithmetic. No SES-, age- or gender-differences were revealed.

3. Reasons for students' attitudes towards the ILS practice

(i) The main reasons for liking the ILS work (as rated by students, in decreasing order):

In the WICAT system:

Chosen in answering the questionnaire by 80%-90% of the students: The immediate positive feedback for correct solutions; liking to work on computers; liking to type on the keyboard rather than writing on paper; and the variety and change of activities provided by the WICAT curriculum.

In the 70%-80% range: The competition induced by the computer work; getting easy work for practice; and receiving help from the computer with mistakes.

In the 60%-70% range: Getting frequent evaluations by the computer; and learning new things through computer practice.

In the 50%-60% range: Getting practice in arithmetic; and new work not done in class.

In the TOAM system

In the 70%-80% range: The immediate positive feedback for correct solutions; learning new things (solving new types of problems) through computer practice; liking to work on computers; and the belief that the computer practice helps in class arithmetic.

In the 60%-70% range: Getting practice in arithmetic; and getting to practice difficult examples.

In the 50%-60% range: The mixture of examples of different types; typing on the keyboard rather than writing on paper and getting frequent evaluations by the computer.

In the 40%-50% range: The change from the classroom to the computer lab, and liking that the computer shows one's errors.

In the 30%-40% range: Competition with classmates; the computer provides easy examples; and the computer provides the answer when the student does not know it.

(ii) The main reasons for disliking the ILS work (in decreasing order):

In the WICAT system:

In the 70%-80% range: Getting the same work for review again and again; being given low scores by the computer.

In the 60%-70% range: Frequent repeats by the computer of directions and instructions; the computer is slow in its presentations; making errors; getting to solve many examples already known; getting too difficult work.

In the 30%-50% range: Getting too easy work; new work not done yet in class; getting practice in arithmetic; and competing with other students.

In the TOAM system:

In the 60%-70% range: Getting too little time to think (time limitation); the computer does not permit correction of errors (typing a digit is final); and error messages.

In the 50%-60% range: Getting too easy work; competing with other students.

In the 20%-40% range: Underevaluation by the computer; the computer does not teach how to solve an impasse; the computer work does not help in class arithmetic.

In the 10%-20% range: Getting too difficult work; the mixture of types of examples; getting practice in arithmetic; and being evaluated frequently on the computer.

To summarize, the primary powerful factor, showing across different ILS's in attracting students to learn with a computer is the positive feedback printed on the screen immediately on completion of each task. Other factors common to the two systems investigated are: using the keyboard rather than writing on paper, liking to work with computers, getting frequent evaluations by the computer, and the competition induced by the ILS work. Students dislike primarily the time limitation (in TOAM), and the fact that making an error affects the frequency of positive feedback and results in underevaluation. In both systems approximately half of the students don't like to get easy work nor do they like the competition that the ILS induces.

(c) Instructional Design and Human-engineering Issues of ILS

1. Encouraging Cooperation or Competition

Both cooperation and competition--can provide powerful motivations for learning, and both can be employed in ways either detrimental or beneficial to students' learning. Thus, when designing an instructional learning system, special attention should be given to factors that either encourage or discourage competition.

The software and the method of operation of two Israeli ILS's were examined to identify factors that either encourage or discourage competition among students [10].

Factors identified as encouraging competition. These consisted primarily of the individualized evaluative information printed either on the screen or in the weekly computerized class report.
(i) For the screen printout information: the normative level of the practice that the student receives; the percentage of correct responses during the session; and verbal statements of encouragement either after each single exercise or as a summary of the performance throughout the full session.
(ii) For the computerized class report: the individualized grade-equivalent level of performance in each of the arithmetic strands and the mean performance across all strands. This report provides also the mean performance of all students in the class and thus it allows the comparison of the performance of each student to that of the rest of the students in the class and to the class' mean performance.

Students proved to compare even individualized information that had nothing to do with the their cognitive performance, such as the cumulative number of ILS sessions or the number of exercises presented during the session.

Competition is encouraged through social comparison processes. When students are able to compare their performance to that of their peers, many of them will try to compete. Individualized computer work was designed to prevent social comparison through keeping private the information on each student's performance. However, our studies show that very often, students do acquire substantial information about their peers' ILS performance.

Sixty-one percent of the WICAT students report that they know who are the most advanced in the computer work. However, only 48% know who are the least advanced. This indicates that students are more interested in the performance of the better students than in that of the weak students, probably for purposes of social comparison and competition. Students' sources for this information are what the teacher or other students say, and watching the screen of other students.

In TOAM approximately 70% of the students indicate that they know which students are the most advanced in the CAI work and approximately 50% know who are the least advanced [10]. Students attribute their information about other students' achievement in TOAM's work to several sources: the level of performance in class arithmetic, which many students believe to be the same as in the CAI work; the screen performance of the other students; and the teacher. Indeed, our observations identified teachers who publicly complimented the students who advanced most, or who publicly named those students who performed at the lowest level.

Factors identified as encouraging cooperation. These consisted of factors that either reduced or completely eliminated the pressure on students to achieve:
(i) Lack of timing of exercises. Students who were called upon to help others were able to do this without being penalized (through exercises evaluated as "wrong" because of exceeding the time limit). Thus, the absence of time limitation encouraged peer cooperation and help;

(ii) The absence of any numerical evaluation either on the screen or through a class computerized report. In the instructional learning system that did not provide these evaluations, students' drive to do better than other pupils was significantly reduced;
(iii) Computer games sporadically incorporated into the software. This feature showed to decrease tension and to encourage the feeling that one does not need to advance fast in the hierarchical levels of practice; and
(iv) The option to make computations on paper that was available only in one of the two systems investigated enabled the better students to help and guide those who needed it by showing on paper how to solve particular exercises.

In summary, students' competitive or cooperative behavior in their ILS work diverged from the intentions of the respective systems' designers. One of these systems was originally designed to enforce individualized, non-competitive work. The designers of the other system did not entertain any considerations of cooperation versus competition in their planning. However, our study [10] shows that the first system encourages students to compete in the CAI work whereas the other system minimizes social comparisons and competition among students, induces a relaxed working atmosphere, and fosters student cooperation and peer help in the computer work.

Aptitude-related effects of competition: low achievers do suffer from their frequent failures in solving the computerized tasks and from their low performance, in either instructional learning system--competitive or cooperative. Competitive ILS environment fosters competitive behavior on the high achievers. A noncompetitive learning environment produces the same low-competitive behavior for all achievement levels.

SES-related effects of competition: No difference on measures of competition were identified between students of high- and low-SES. However, the instructional learning system that induces a competitive environment produces negative feelings in disadvantaged students [10].

Gender-related effects of competition: Boys were found to be more competitive than girls in each of the ILS's investigated [8,10].

2. Applying Time Limitation for Entering Answers

Of all types of instructional media equipment available in schools, the computer is unique in its capability to count time. This feature allows limiting the time for entering an answer in CAI work. Indeed, many of the computer software programs used in schools today, particularly those designed to bring the child to a certain degree of automaticity in arithmetic techniques, limit the answer time. Our study [15] investigated the effect of a substantially increased answer time on students' performance, in the TOAM system. This showed to dramatically improve the performance of all students in the short run (within two months of the increase), while in the long run the improvement decreased.

In the WICAT system, the majority of activities have no time limit. There is a particular activity that enables students to choose between three options of speed for typing in the answer (that is, to choose the time limit for an answer). When students were asked which speed they most frequently choose, the great majority (86%) testified that they usually chose the slowest speed. Approximately 50% don't ever choose any other speed than the slowest [16]. This finding indicates that students do not like to take risks and prefer to "go for safe results".

Aptitude-related effects

While the better students rarely failed to type in an answer that they knew within the time limit, lower-achieving students frequently failed to respond in time, even in cases where they had stated aloud the correct answer [2,4,5,6]. Boredom, fatigue, difficulties in concentration, slow response time, playing games, looking at other students' computer display--all these behaviors caused these students to miss the time limit for entering their answer. Our study suggests that students with low aptitude for arithmetic need more time for typing in a solution than high-aptitude students.

A large scale experiment [15] revealed that a certain proportion of students of all ability range systematically missed the time limit (made "time-limit errors"). Our intuition would suggest that time-limit errors are made primarily by low achievers. However, the study [15] shows that many medium achievers also make this type of error. Among the students who made a large proportion of time-related errors, 5% were high achievers; 38%-- medium achievers, and 57%--low achievers. Because only few high achievers make time-related errors, timed solutions is one of several ILS instructional design factors that make the work with ILS more effective for better students than for the others.

In the long run, a differential effect of time-limit increase on students' performance in relation to their aptitude was identified. Four months after the time increase, high achievers either increased their benefits or at least kept improvement at the same level as that in the first two months, whereas low achievers showed a decrease in the benefits. Still, low achievers improved their performance as a result of the increase more than the high achievers. Our main conclusion is that the increase in time limit in the long run, benefitted primarily those who initially made a large percentage of errors due to the time limit.

To conclude, our studies suggest that time limitation should be included as a default feature in the design of any ILS system. The length of "wait time" for a student's answer should be adjustable to the level of difficulty of the exercise involved and be adaptable to the aptitudes of the individual student. Special attention should be given to providing the slow learners with sufficient time for the completion of each task without too much pressure. Students of low ability or those identified by the computer as making a large proportion of errors due to time constraints, should be assigned longer time for entering an answer than other students.

3. ILS Hardware and Software-related Issues

Students' problems with the hardware- and software work

Many WICAT students (67%) admitted that they experienced getting an error-feedback even when they knew the answer. This happened primarily because of mistakenly pressing the wrong keys (followed by not checking on the screen what they typed before pressing the RETURN key), or because of missing the time limit where available. Fifty percent experienced reversing the order of the figures in the answer as the reason for a wrong answer [13]. In TOAM, we identified similar types of problems, primarily through students' observations [2,4,6] .

Motivational-instructional design factors

In the WICAT software, the activity the children like most (45% of the students) is named Think Fast. The main reason (chosen by 77% or the students) for liking this activity is the picture stories (cartoons) that come with this activity.

The main reasons for liking other types of activities are the choice of the speed (66%), the feature of racing against time (51%), moving number-representing blocks (54%) or moving money coins (45%) on the screen. These findings indicate that children like to be actively involved in what happens on the screen. They enjoyed choosing and moving things. However, they are shown to be attracted primarily by the fantasy involved in the cartoons.

The main reasons for disliking particular activities were: The time limit (29%), and the pan scales going up or down when trying to equate numbers (21%).

4. Using Paper-and-Pencil Work While On-Line

In the WICAT and SEMEL systems, students may use their notebooks with pen or pencil while on-line, whereas in TOAM, because of the time limit, they cannot write on paper while on-line. Eighty-one percent of the WICAT students like to make computations on paper and believe that it helps them with the computer work. In TOAM, 53% of the students prefer class arithmetic to the computerized arithmetic. This, because in class, and writing on paper, they can solve examples in any method, using any steps they like and in any order that is convenient for them whereas on the computer they are required to conform to a particular method of typing in a solution. The use of computations on paper is one of the factors that contribute to relaxed and non-competitive work in the SEMEL system [10] because students can help one another by showing their paper-and-pencil solutions.

(d) Students' ILS-Related Behavior

When getting on-line problems which they are unable to solve, almost all WICAT students try first to invest thinking efforts in finding the solutions, or else they call the teacher for help while on-line in the computer lab [13]. A smaller proportion of students, on encountering difficulties, use the option to get help hints provided by the software, try to learn from the correct answer provided by the computer (65%), or ask the teacher later, in the classroom. Approximately half of the students admit guessing the answer. Forty-six percent look for help at home and 37% ask other students in the classroom. Approximately two thirds of the WICAT students either use the correct solutions printed on the screen (after the student errs in his/her typed-in answer) to learn how to solve the examples, or examine their typed solution before pressing the RETURN key, or use the HELP key to get hints for solutions, or believe that these hints help them understand and learn. Almost half of the WICAT students use the possibility to choose from several options provided by the system.

Of the TOAM students, 88% state that they make efforts to think and figure out the solution algorithm when receiving unfamiliar types of examples. However, 68% ask teacher's help on-line, 62% guess the answer, 50%, 36% and 25%, respectively, ask for help from the teacher in class, or from parents or siblings at home, and classmates on-line. Twenty-four percent type a random answer and try to deduce the correct algorithm from the solution provided by the computer, and 14% just type in any number without guessing or deducing it.

These findings indicate that a large proportion of students does not use the possibilities for choice or for own decisions in their learning. These students are not independent learners, are not able to control their learning and need external guidance and support.

(e) Teachers' ILS-Related Behavior

1. Teachers' Use of the Class Report

TOAM teachers use the information included in the weekly-printed computerized class reports in three major ways [12]:

(a) For student evaluations; Almost all the teachers whose students work with TOAM, use the computer reports as a major source for students' grading, in addition to the evaluations of class performance.

(b-c) For individualizing students' work and for assigning students to homogeneous learning groups; The computer reports are used for these instructional purposes by approximately three quarters of the teachers. The individualized work on the basis of the computer reports is done using flashcards, each containing several exercises of the type identified as problematic for the student in the ILS work. The assignment to homogeneous groups is also done on the basis of the

computer reports which can be printed in a version that lists students in a decreasing order of performance. This kind of printout enables the teacher to easily select students whose ILS performance is of a similar level.

2. Teachers' Attitudes Towards the Class Report

Almost all teachers (97%) believe that the computer reports contribute both to their own work as well as to their students' learning. Of ten possible reasons for advantages of the ILS work listed in a questionnaire [12], the two items that were rated highest by almost all teachers were: "The individualized work and feedback" and "The diagnosis of performance and problems", that is--teachers highly appreciated the information provided by the computer reports.

3. Effects on Teachers of the ILS Work and the Class Reports

The individualized ILS work along with the weekly computer report show to make a substantial impact on teaching methods. A very large proportion of teachers admit that they have modified their frontal teaching methods in order to adjust to the individualized style of the ILS work. Almost all teachers (93%) use the report evaluations combined with class tests for grading [11].

To summarize, the frequent provision of a computer class report is a crucial tool for the individualization of instruction through the ILS work. The report should contain information about the mean performance of the whole class as well as information about the performance of each single student and the particular problems he/she encounters in the computer work. The report should be printed in a form that makes it easy for teachers to identify the important information and it should provide several options for printout (e.g., in alphabetical order, in decreasing or increasing levels of performance across all strands, and for each single strand separately). This type of report appears to serve as a major tool for teachers' adapting treatment to the individual student and encourages teachers to switch from frontal instruction to more individualized methods.

4. Competition-related Teachers' Behavior

The level of competitiveness induced by an instructional learning system affects teachers' behavior. In an instructional learning system with particular features that were found to encourage competition, the teachers also encourage competition among students, while the case of an instructional learning system that was identified to discourage competition and encourage cooperation among students (SEMEL), the teachers do the same. That is, teachers adjust their competition-related behavior to the behavior induced by the computerized system.

The publication in school of the weekly computer class report has been found to promote competition among teachers of parallel classes at the same school [2,17].

5. Teachers' Perceptions of the Effects of the ILS Work on their Students' Learning and on their Own Work

Almost all teachers (97%) are satisfied (27% of these are highly satisfied) with their students' ILS work in the TOAM system. Most teachers (86%) believe that the good students gain most from the computerized practice and the low achievers least.

The teachers assess that the ILS work not only does not save their time but that it increases approximately by 4 hours their weekly load.

(f) Decision Making through the Computerized Management of Students' ILS Practice.

Following the model of decision-making in statistical hypothesis testing, we may classify the decisions made by a computer-managed practice system in arithmetic with regard to the correctness of a solution of an exercise or of a problem as follows [16]:

(a) **Accept** a student's answer as correct when the student knows the correct solution algorithm **and** understands the underlying concepts;

(b) **Reject** an incorrect answer when the student either does not know the correct solution algorithm **or** does not understand the underlying concepts; and

(c) Make only a minimal proportion of decision errors either of TYPE I (**reject** an incorrect answer when the student does know **and** understand--c1) or of TYPE II (**accept** a student's answer as correct when the student either does not know **or** does not understand--c2).

The observations in our studies revealed problems in all four categories of this decision-making model [2,4,5,6].

(a) Problems in this category arise when a solution is evaluated by the computer as incorrect without identifying the causes for error.

(b) Problems in this category arise when a solution is evaluated by the computer as correct for the wrong reasons. This happens, for example, when the student uses a particular solution algorithm, with full understanding, but that algorithm does not satisfy the objectives of the particular exercise within the context of the ILS curriculum, or may even be wrong mathematically.

None of the ILS's we observed (and probably not many other similar systems of this type) appropriately handles students' lack of knowledge or of understanding after an incorrect answer has been identified by the computer. When students err, they should be informed as to the source of their error as well as being shown how to solve the exercise correctly. To provide this type of informational feedback, the ILS should be able to identify the type of error made along with its source, that is, to differentiate an occasional error from an error caused by the absence

of knowledge or by some misconception; or from errors caused by affective, socio-psychological, or human-engineering factors. Identification of the source of error is very important for the adaptive response. However, the machine is not yet able to reform this type of identification, and generic capability for such diagnosis is probably not achievable.

(c1) Reasons for this type of error are usually related to human engineering factors. Not much is known about difficulties in learning arising from the interaction of children with computers. Our observations identified three groups of factors that cause TYPE I decision errors:

(i) Maladjustment of the Student to the Learning Environment.

Work in a computer environment differs in several aspects from regular paper-and-pencil work in class or home. Our observations reveal that different computer systems with different hardware, software and mode of operation produce different learning environments, each responsible for some type of student maladjustment or for problems of interference with the class or home environments. Some children prove to adjust well to the particular style required for working with a particular computer system whereas others show problems in adjusting, particularly when the hardware or software are not highly "user friendly".

(ii) Affect-Related Errors.

Students who are unmotivated, bored, indifferent or tired often work mindlessly (e.g., guess the answer). As a result, they may enter wrong answers even for problems they can solve when ready to put in more thinking effort. This mindless behavior is evident particularly when students are faced with the need to apply problem-solving strategies.

(iii) Behavioral-Related Errors: For example, game playing; fatigue; and competition.

(c2) It happens that students receive practice exercises which they do not know to solve yet they do type in the correct answer. We have observed two categories to these cases:

(i): A correct solution when the student does not know the algorithm for solution and does not understand the underlying concepts.

This behavior has been observed in several situations:

- The student remembers the computer-produced final answer for a prior exercise of the same type;
- The student enters a random digit which proves to be correct.
- The student makes an educated guess which proves to be correct.
- Either the teacher or another student tells the student the correct answer
- The student uses a technique which works for a special case but not as a rule.

- The student uses a totally erroneous technique which incidentally produces a correct solution.

(ii): A correct solution when the student identifies the correct algorithm for solution and applies it correctly but without understanding of what he/she is doing and why.

This has been shown to happen in the following situations:

- The student extrapolates from familiar to unfamiliar operations, by imitating worked examples, extending the pattern of arithmetic operations to new notations, or preserving the pattern of a sequence in a new notation.

- The student uses trial-and-error techniques to deduce algorithms from final answers for exercises he/she does not understand.

The inaccuracies in the judgement of students' answers, as described so far, lead to the mastery requirements of particular topics in the ILS work not being met. This situation, in turn, leads to an inappropriate promotion of students.

The inaccuracies in students' promotion by the software may again be divided into four categories [16]:

(a) promote when the student does master the type of exercises in the sequence.

(b) do not promote (branch: demote, repeat, or go to a remedial loop) when the student does not master the type of exercises in the sequence;

(c1) error of TYPE I: do not promote when the student does master the type of exercises in the sequence; and

(c2) error of TYPE II: promote when the student does not master the type of exercises in the sequence.

The TYPE I error (c1) is the most widely prevalent of these four categories. Our study [6], examining over 100 students, and Osin & Nesher's (1988), examining a representative sample of over 1,800 students, show that students perform the same tasks on paper-and-pencil at substantially higher Levels than their current ILS Level. For some sequences of arithmetic exercises, all children performed better on paper than with the computer. For others, the effect was much smaller but still significant [6]. These findings indicate that the existing ILS management systems malfunction to a certain degree in promoting students to their appropriate level of knowledge.

Wrong decisions of TYPE II (c2) also occur, although to a lesser extent [6], and they are identified by the opposite phenomenon--the student advances in the ILS work to Levels higher than in his/her paper-and-pencil performance. This situation arises when a student develops a flawed or incomplete algorithm that works for some exercises of a sequence but not for others,

and it may happen that the proportion of exercises for which the wrong algorithm works satisfies the mastery requirements.

Conclusions

The ILS's that are available in schools are not mature yet. Some have a good curriculum but an insufficient management system. Others have a good computerized management system but their curriculum does not satisfy the criteria for the currently required learning goals. For example, the current goals in mathematics education are to reduce the emphasis on computations and increase the emphasis on the promotion of understanding and of strategies. However, many of the more veteran ILS's provide mathematics work in the traditional line of repetitive drill and practice.

Another problem is the actual difficulties in integration with the regular school curriculum. If a student advances in accordance with his or her own potential, all students in a class work on a very spreadout curriculum of several grade levels. On the other hand, class instruction does not exploit effectively the individualization made possible by the computerized work.

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